Off-the-Shelf, Real-Time, Human Body Motion Capture for Synthetic Environments

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Abstract

Human body tracking is a very important issue in synthetic environments, pervading every application. The repercussions of not providing adequate methods of motion capture for the user's head are often severe, ranging from user disorientation to simulator sickness. The repercussions of not providing adequate motion capture for the rest of the user's body, while not as severe, are often as distracting. If the user is to interact in a natural way with a synthetic environment, the interface must be intuitive, accurate, responsive and transparent. There are many off-the-shelf motion capture systems available, employing a wide variety of cutting-edge technologies. However, they all have unique problems which render them either unsuitable for real-time applications or unsuitable for tracking the human body. This paper addresses the current methods of synthetic environment motion capture and evaluates their effectiveness when applied to real-time human body tracking.

1. Introduction

For a number of years, researchers have been attempting to create believable three-dimensional worlds inside a computer for a variety of purposes including data visualization, computer-aided design, training of all sorts, the control of remote robots and manipulators (tele-operation), artificial enhancement of the real world, and entertainment. These researchers, for the most part, have failed to hit the 'total immersion' mark, although consumers are generally willing to overlook inadequacies while exploring new technological advances.

There are various reasons why synthetic environments have failed to reach the goal of 'total immersion'. One of the main reasons is the lack of a natural interface between the computer and the human machine. One might say that people have grown quite accustomed to using a keyboard and a mouse to communicate with their computer, and indeed, some people are *very* adept at operating a computer using these devices. However, keyboards and mice are not present when people exit their domiciles and interact with the real world. People use all of their senses (the five basic: sight, hearing, touch, taste and smell) to receive information about the world they live in and they use their body motions to act on objects in that world.

The fact that people have so many senses to sample the world's information stream and that they use their entire bodies to interact with that world is the reason that synthetic environments fall short. There is a saying which states that, "You can fool some of the people all of the time, and all of the people some of the time ,but you cannot fool all of the people all of the time." This saying is particularly applicable to the human senses. In fact, it would be very difficult to fool *all* of the senses at *any* time. While fooling the human visual and auditory senses has become fairly routine for synthetic environment researchers, fooling the other human senses has been found to be very difficult. There is much work to be done on the human-computer interface.

The issue of allowing people to *interact* naturally with a synthetic environment has been the subject of much debate. One thing is clear: If the user is to interact with a synthetic environment in a way which is *perceived* to be natural, then an interface device must be provided which is capable of determining what the user is doing without interfering with their motion or encumbering their body. This device must accurately capture the user's motions and supply them to the synthetic environment generator with an update rate sufficient to provide the user with real-time response to their actions.

This paper addresses the issues of motion capture in synthetic environments and the current off-the-shelf products which allow varying degrees of human body tracking. While most motion capture equipment is not limited to capturing the motion of the human body, this paper emphasizes human body tracking since it is a necessary component of a *natural* human interface to synthetic environments.

2. Human Body Motion Capture Fundamentals

Figure 1 shows the minimum configuration of human body parts which must be tracked to ensure that all significant body motions are detected. In general, if we desire to track the entire human body, there are fifteen major parts to track independently. The major portions of the body that must be tracked are the head (normally tracked as an input to the graphics rendering software used to drive a head-mounted display), torso-clavicle region, abdomen-hips region, upper legs, lower legs, feet, upper arms, lower arms and hands.

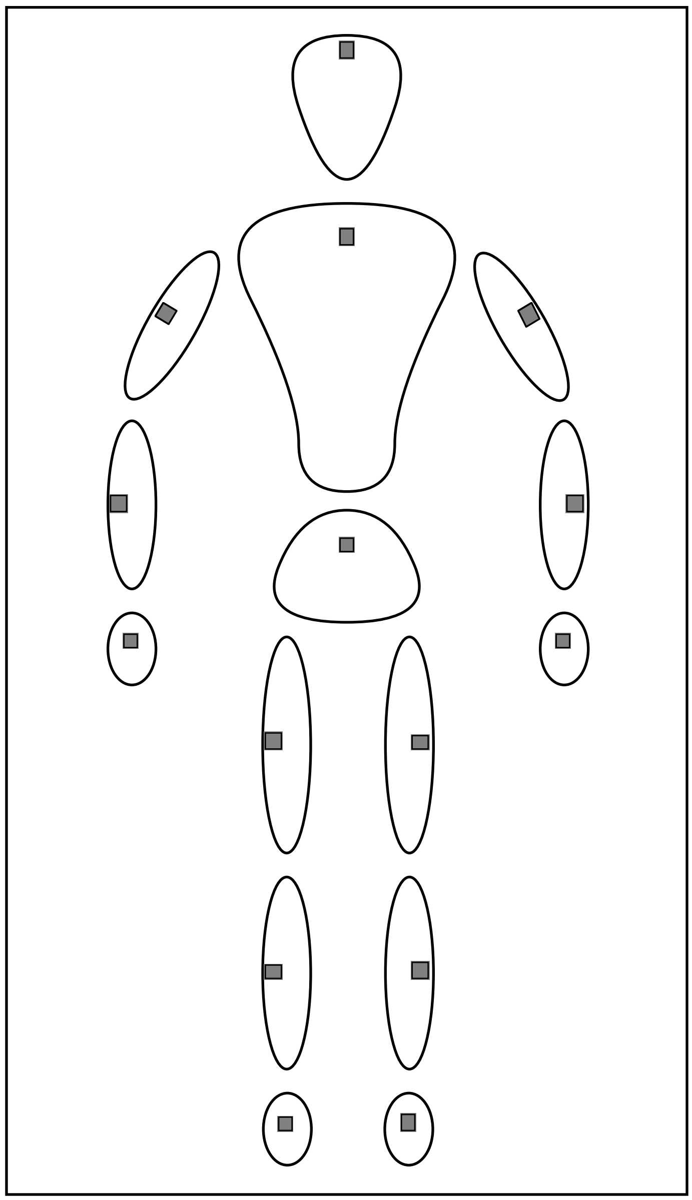

Figure 1 -- Minimal Human Body Tracking Configuration

While more body parts than those shown in Figure 1 may be tracked, tracking any more than these may result in diminished returns. For instance, it may not be worth the extra time required to track the user's back and shoulders as several separate entities. This is, of course, dependent upon the user's application. If the user's application requires the separate track of the shoulders and back or the separate track of the parts of the foot, then the motion capture system must be capable of adapting to these needs. When determining the number of body parts to track, the designer must not forget a keystone issue of body tracking: Don't encumber the user!

There is also a trade-off between the time required to process the physical information from the parts of the body being tracked and the time required to calculate the positions of the parts of the body that are not being tracked. For every body part that is not tracked, the system must estimate its position using inverse kinematics. Inverse kinematics algorithms are computationally complex and require more computing power than measuring the positions of the parts directly. For instance, direct tracking of only the shoulder and hand positions requires that the position of the elbow and the joint angles of the shoulder, elbow and wrist be estimated. This is possible but not as physically accurate or computationally efficient as tracking the parts directly.

Tracking the body parts directly also has its draw-backs. First, placing sensors on the body encumbers the user. One of the goals of a synthetic environment is to completely immerse the user in a believable world where it will seem natural to be there. Placing more sensors than necessary on the user's body is contrary to this goal. In addition, the cost of a body-tracking system varies almost linearly with the number of body parts tracked; more sensors equates to higher cost.

The information required from each body part tracker varies. There are some devices which provide all 6 degrees of freedom (DOF) (spatial position and orientation) for each tracked object. This is overkill for tracking the human body (or any other articulated body). For the fifteen body parts in Figure1, it can be shown that only one base part must be tracked with a 6 DOF tracker. All other body parts need only be tracked using 3 DOF (orientation only) and then articulated relative to the base part. After all, this is how the human body works; drag on the ring in someone's nose and their entire body is obliged to follow!

Using this scheme and the configuration of Figure 1 results in a system that can adequately track the human body using only 48 DOF (NOTE: degrees of freedom are "...independent position variables which would have to be specified in order to locate all parts of the mechanism." [Craig, 1989] For the purposes of this paper, 6 DOF refers to the following variables: The earth-fixed orientation angles -- azimuth, elevation and roll -- and the earth-fixed spatial position variables -- x, y and z.).

Some systems, usually mechanical in nature, track body *joint angles* rather than body part positions and orientations. While this method leads to a direct and reliable means of tracking the human body, it is typically very encumbering to the user. Most of the systems that use this method are exo-skeletal (attached to the body to measure joints angles directly). These systems are very sensitive to the differences between users' bodies and are reliant on the size of the user's body parts (upper arm, forearm, etc.) to determine the spatial positions of the user's extremities. Thus they must be re-calibrated for each new user to ensure proper operation.

There are various means of capturing object position and orientation which are currently employed in the field of synthetic environments. Each has weaknesses which make it unsuitable, or strengths which make it particularly suitable, for a range of applications. The next section focuses on the various means of human body motion tracking, their technological capabilities, advantages and problems.

3. Current Methods of Motion Capture

A. Mechanical

Mechanical position tracking devices can be separated into body-based (exo-skeletal systems) and ground-based systems. Body based systems are those which are mounted on, or carried on, the body of the user and are used to sense either the relative positions of various parts of the user's body or the position of an instrument relative to a fixed point on the user's body. Ground based systems are typically not carried by the user but are mounted on some fixed surface (i.e.. the user's desk or the floor) and are used to sense the position of an implement relative to that fixed surface.

Body-based systems are typically used to determine either the user's joint angles for reproduction of their body in the synthetic environment, or to determine the position of an end-effector (the user's hand, foot, etc.) relative to some point on the user's body. Since the body-based systems are used to determine the relative position between two of the user's body parts, the devices must somehow be attached to the user's body. This particular issue has raised many questions: How is the device attached to the body in a way which will minimize relative motion between the attachment and the soft body part it is being attached to? How are the joints of the device aligned with the user's joints to minimize the difference in the centers of rotation (a significant source of errors)?

Some other problems associated with body-based tracking systems are specifically caused by the device being attached to the user's body. These systems are typically very obtrusive and encumbering. They do not allow the user complete freedom of movement and they detract from the possibility of the user experiencing complete immersion into the synthetic environment. Body-based systems are, however, quite accurate and do not experience problems like measurement drift (the tendency of the device's output to change over time with no change in the sensed quantity), interference from external electromagnetic signals or metallic devices in the vicinity, or shadowing (loss of sight of the tracked object due to physical interference of another object).

Ground-based systems are typically used to determine the position and orientation (6 DOF) of an implement manipulated by the user relative to some fixed point not on the user's body. These devices are not typically attached to the user's body, provided the user can grasp the manipulator in a rigid manner. Like body-based mechanical systems, they are typically very accurate and are not plagued by measurement drift errors, interference or shadowing.

Ground-based systems do suffer from one thing which the body-based systems do not: They confine the user to work within the space allowed by the device. Usually this means that the user is confined to work in a space the size of a large desk. If the application does not require the user to move around much throughout the task (i.e.. the user remains seated), this is not usually considered a problem.

Mechanical tracking systems are the best choices for force-feedback (haptic) devices since they are rigidly mounted to either the user or a fixed object. Haptic devices are used to allow the user a 'sense of touch'. The user can feel surfaces in the synthetic environment or feel the weight of an object. The device can apply forces to the user's body so that the user can experience a sense of exertion. Ground-based systems are typically the best choice for incorporation of haptic devices due to their rigid mounting on a fixed surface.

Mechanical tracking systems also typically have low latencies (the time required to receive useful information about a sensed quantity) and high update rates (the rate at which the system can provide useful information) [NRC, 1995].

B. Electromagnetic

Electromagnetic tracking systems are currently the most widely used systems for human body tracking applications. They employ the use of artificially-generated electromagnetic fields to induce voltages in detectors attached to the tracked object. Three orthogonal electromagnetic fields are generated by a stationary transmitter. These fields interact with the three orthogonal coils in each detector attached to the tracked object. Induced voltages are generated in the detector coils which are proportional to the spatial orientation of the detector relative to the transmitter.

These tracking systems are fairly inexpensive and can be used to track numerous objects (body parts) with acceptable position and orientation accuracies (typically on the order of 0.1 inches and 0.5 degrees). They do not suffer from shadowing effects, but are typically plagued by a sensitivity to background magnetic fields and interference caused by metal devices in the vicinity. Since they are reliant on the magnetic fields generated by the transmitter, these systems are called "sourced" systems and have a limited tracking area, typically the size of a small room.

Electromagnetic tracking systems can employ either AC or DC magnetic fields. Those employing DC magnetic fields are typically less sensitive to interference caused by metallic objects in their vicinity [NRC, 1995].

C. Acoustic

Acoustic tracking systems utilize high frequency sound waves to track objects by either the triangulation of several receivers (time-of-flight method) or by measuring the signal's phase difference between transmitter and receiver (phase-coherence method).

The 'time-of-flight' method of acoustic tracking uses the speed of sound through air to calculate the distance between the transmitter of an acoustic pulse and the receiver of that pulse. The use of one transmitter on a tracked object and a minimum of three receivers at stationary positions in the vicinity allow an acoustic system to determine the relative position (3 DOF) of the object via triangulation. This method limits the number of objects tracked by the system to one. An alternative method has been devised in which several transmitters are mounted at stationary positions in the room and each object being tracked is fitted with a receiver. Using this method, the positions of numerous objects may be determined simultaneously.

Note that the use of one transmitter (or one receiver) attached to an object can resolve only position (3 DOF). The use of two transmitter (receiver) sets with the same object can be used to determine the position *and* orientation (6 DOF) of the object. The desire to track more than just the position of an object suggests that the second method (multiple stationary transmitters with body-mounted receivers) may be preferable.

The other method of acoustic tracking, phase-coherent tracking, may be used to achieve better accuracies than the time-of-flight method. The system does this by sensing the signal phase difference between the signal sent by the transmitter and that detected by the receiver. If the object being tracked moves farther than one-half of the signal wavelength in any direction during the period of one update, errors will result in the position determination. Since phase-coherent tracking is an incremental form of position determination, small errors in position determination will result in larger errors over time (drift errors).

Some problems associated with both acoustic tracking methods result from the line-of-sight required between transmitter and receiver. This line of sight requirement obviously plagues the devices with shadowing problems. It also limits their effective tracking range, although they typically have better tracking ranges than electromagnetic systems. Unlike electromagnetic systems, they do not suffer from metallic interference, but they are susceptible to interference caused by reflections of the acoustic signals from hard surfaces and interference from ambient noise sources.

D. Image-Based

Image-based systems are lumped into two broad categories; those that use active targets and those that use passive targets (or no targets). Targets are devices which, when placed on the object to be tracked, are visible to the tracking system. In both systems, cameras are used to record the object being tracked and detect the motion of the targets on the object. Typically, multiple cameras are used so that the object may be tracked in three dimensions instead of just two. While only two cameras are required to achieve three dimensional tracking, more are typically used to provide redundancy in an effort to prevent shadowing of the targets.

Image-based systems which use targets attached to the object being tracked are called marker systems. The targets used in active marker systems are typically infrared light-emitting diodes (IRED's) which emit light visible to the system but not to the user. As in acoustic systems, the detectors, or cameras, may be placed either on the tracked object or at stationary points around the object. Obviously, cameras placed on a human body would be more obtrusive. For this reason, placing the targets on the body and the cameras at stationary points in the room is normally preferable.

Each camera is placed so that it has a unique perspective of the targets. Thus triangulation of the targets can be used to track them in three dimensions. This technique reveals the first major problem with image-based systems; determining correspondence of targets in each of the camera views. In order to use several views of the same target to triangulate its position, a target must be distinguishable from the other targets around it. One method of distinguishing the targets is to pulse their outputs in sequence with camera detection. Once the targets can be distinguished, the remaining question is, how many may be used simultaneously. If orientation of the object is desired in addition to position, at least two targets must be placed on the same object and their difference in position used to determine the orientation of the object.

Image based systems rely on the cameras being able to detect the targets at any given instant in time. If an object passes between a marker and a camera during the detection interval, the camera will fail to detect the marker. If this condition persists for a long enough period of time, tracking of the object will fail. Failure in tracking a human body may be caused by as simple a thing as one body part obscuring another from all of the camera viewpoints. This effect is called shadowing. As mentioned before, shadowing may be minimized by the use of multiple, redundant cameras, but it cannot be totally eliminated.

As would be expected, multiple-source image processing requires a level of computational complexity not required by the other methods of motion capture. The combination of the computational requirements and the use of multiple high-resolution cameras makes image-based tracking one of the most expensive body tracking solutions available.

While they are not yet feasible for accurate body tracking in synthetic environments, lower-cost, image-based systems would be very suitable for gesture recognition systems. For example, the detection of hand or arm signals from the user directing the computer on which way the user wants to travel in the environment.

E. Optical

There are numerous means of optical tracking, each employing a slightly different technique with differing equipment. This section will give a short synopsis of the most prevalent methods followed by the pros and cons of optical tracking methods in general.

1. Position-Sensing Detector (PSD) Systems:

Position-sensing detectors (PSD's) are photo-electronic devices, each made from a slice of silicon doped with materials which form a PN junction. The PN junction is light sensitive and incident light will cause it to generate an electrical current. This electrical current is inversely proportional to the distance between the incident light position and the sensing electrode. When a light source is positioned over the device, its position in the x-y coordinates of the PSD may be determined by comparing the relative strengths of current signals from various attached electrodes.

When several of the PSD's are utilized from various positions, triangulation using the signals from the devices may be used to determine the 3 DOF position of a light source. This method is very similar to the image-based tracking method described above, the difference being the sensing device. It suffers from all of the same problems which afflict image-based tracking systems.

2. Structured Light Systems:

Typically in structured light systems, a laser beam and beam-forming optics are used to create a known pattern of coherent light which is then scanned across the scene. A camera is used to capture the scene as the light is scanned across it. The intersection of the camera plane and the lased light beam reflecting from the surfaces of the scene creates a three-dimensional coordinate system [NRC, 1995].

3. Laser Radar:

The concept of laser radar is similar to that of time-of-flight acoustic systems. A laser is used to scan an object and the returning, reflected laser light is detected. The difference in time between sending the beam and receiving the reflected light is a function of the range to the reflecting surface. If the beam is scanned over a scene, a three-dimensional picture of the scene is generated [NRC, 1995].

4. Laser Interferometry:

This system uses a steered laser beam to track a retro-reflector mounted on the object being tracked. The angle subtended by the steered laser beam, in two dimensions, and the time-of-flight of the lased light forms a three-dimensional space. Another method uses several lasers, each tracking a retro-reflector from a unique perspective, to form the three-dimensional space [NRC, 1995].

In all of the structured light tracking methods, the use of lased light tends to make the system extremely accurate. However, none of the above systems is capable of tracking more than a few objects simultaneously, and all are susceptible to shadowing. These problems tend to make purely optical tracking methods insufficient for real-time tracking of the entire human body.

F. Experimental Methods of Motion Capture

1. Inertial

The double integration of three-dimensional linear acceleration has been used for a number of years to determine navigational position. Until recently, the sensors used to measure linear acceleration had been too bulky and heavy, and the double integration of linear acceleration included sufficient errors to make it undesirable for human body tracking.

Now several companies have begun producing tiny micro-machined accelerometers which, given the time for development of application specific integrated circuits, would be small and light enough for use in inertial human body tracking. There are two versions of these sensors. One version measures only one dimension of linear acceleration. The other version uses a differential combination of two dithered (vibrating) linear acceleration sensors to determine angular rate.

The typical use of such devices is to single-integrate the angular rate sensor output to determine angular orientation, and to compensate for angular rate sensor drift using linear acceleration sensors to determine the direction of the earth's magnetic and gravitational fields. The combination of three orthogonal sets of these two sensors is then used to determine the orientation of the attached object.

While the method of using these sensors seems complicated, the theory behind their use has been around for hundreds of years. It is a proven technique, which has been used successfully for aircraft, ship and submarine navigation for decades.

Inertial body tracking has the potential to be the best method of human body tracking. This is due primarily to the fact that there is no artificial source signal required for operation. The only true signal sensed is the earth's gravitational field, which does not change enough to effect the operation of an inertial tracking device.

The lack of an artificial source means that inertial tracking methods do not suffer from signal or metallic object interference or shadowing. The transmitting of body tracking data via wireless means would also eliminate tethers. The user would be free to move around in the real world with no restrictions, save the range of the data transmitter (which can have a very long range -- consider packet radio or satellite communications). Also, the use of advanced micro-machined inertial sensors and application specific integrated circuits would minimize the encumbrance of the user.

The one major drawback of inertial sensors is their tendency to drift, their tendency to accumulate measurement errors over time. Techniques are available which minimize the effects of drift. The most widely used is a combination of angular rate and linear acceleration sensors which compensates for drift using the earth's magnetic and gravitational fields as a directional reference.

The current rate of advance in inertial sensor technology has the potential of making inertial technology the primary means of human body tracking within the next few years.

2. Spread-Spectrum

Another method of navigational position determination is the use of the Global Positioning System. This technique uses a constellation of satellites orbiting the earth which emit signals intercepted by a navigational receiver. Each signal is decoded by the receiver to determine the exact distance between the satellite and the receiver. Triangulation is then used to determine the receiver's spatial position.

This technology can be adapted to provide a very accurate position determination on a much smaller scale. The construction of a large area (like a football stadium) containing a set of low strength spread spectrum transmitters would allow a suitably instrumented human body the freedom to roam around, while each GPS-style receiver attached to the user's body would determine the position of each limb. The use of two receivers attached to each limb would allow the determination of limb orientation as well as position.

If, as with the proposed inertial tracking system, the positional data was transmitted from the user's body to the computer system via wireless communication means, the user would be entirely untethered, free to roam anywhere within the effective range of the spread-spectrum transmitters.

The primary draw-backs of spread-spectrum human body tracking would be range restrictions and the potential for high-frequency electromagnetic radiation exposure of the user. Also, the initial cost of this type of system is likely to be quite high. As research continues and the technology is made more widely available, the price will fall [Bible, 1994].

4. Recommendations

Examination of the current methods of human body tracking (See Appendix A) reveals that there are very few solutions which will provide the real-time, *full* body tracking capabilities described in section 2 (motion capture fundamentals). Some of the systems, while fast enough to provide real-time tracking, cannot track more than a few objects simultaneously. Others can track many objects simultaneously, but are incapable of providing real-time tracking. Mechanical tracking systems typically fall into the former category, while optical, image-based and acoustic tracking systems typically fall into the latter.

This section summarizes the advantages and disadvantages of several current body tracking systems and makes recommendations for application of these technologies to real-time, full human body tracking for synthetic environment applications.

A. Current Recommendations:

Electromagnetic systems are well suited to tracking the entire human body in real time. They provide accurate, reproducible track of the body in real time. They are simple to set up and operate, consisting of a single stationary transmitter, multiple independent receivers attached to the body being tracked and associated electronics. They have no moving parts and are very durable. The electronics package is fast enough to sample the receivers at rates approaching 120 Hz (the minimum tracking frequency for real-time applications is accepted to be around 30 Hz).

The primary disadvantages of electromagnetic tracking systems are their susceptibility to electromagnetic and metallic object interference, range restrictions resulting from use of a transmitted tracking source and user encumbrance caused by the tether used to transmit tracking data to the host computer system. These disadvantages can be easily overlooked in the short term since most of the current body tracking applications do not require the user to move great distances. However, as the application space of synthetic environments grows, there will be applications which will require the user to be free of movement and range restrictions.

The two companies which currently produce electromagnetic tracking systems are Ascension Technology Corporation and Polhemus, Incorporated. Their methods of electromagnetic tracking are almost identical, with the exception of the source signal. Both use a stationary electromagnetic transmitter and multiple receivers. Polhemus' system uses AC electromagnetic field generation while Ascension uses DC. Ascension claims that their use of pulsed DC fields minimizes metallic object interference. Otherwise, the operating characteristics of the systems are the same.

When used for tracking the entire human body, Polhemus has the clear advantage. Their newest system, ULTRATRACK 120, allows simultaneous track of the entire human body (up to 16 individual parts) in real time, with all of the components collected in one location. The current version of the ULTRATRACK system is tethered, but an untethered version is under development.

The Ascension "Flock of Birds" system has the ability to track the entire human body in real time. However, their tracking system consists entirely of add-ons to their base system. It is not fully integrated like the Polhemus ULTRATRACK system.

Best Currently-Available System:

Polhemus ULTRATRACK 120

(see Appendix A for more information)

It is the authors' recommendation that the Polhemus ULTRATRACK electromagnetic tracking system be used for current synthetic environment systems requiring real-time, full human body tracking, with Ascension's "Flock of Birds" system as a second choice.

B. Near Term Recommendations:

By far the most attractive solution in the near term (within the next two years) is inertial tracking. This method eliminates *all* of the disadvantages of *all* of the current methods of body tracking. It does this by eliminating the need for a source or an external detector. All of the sensors and electronics required would be carried on the user's body. The data collected about the orientation of the user's body parts would then be transmitted, by wireless means, from the user's body to the host computer, eliminating range restrictions and tethering.

Inertial human body tracking is still in its infancy. Angularis Inertial Technologies is the only company that is currently using this method for human body tracking. Their current application of this technology is limited to head tracking for head-mounted-display orientation. Their sensors are still too bulky for unlimited use on the human body. However, given a year of seriously funded development, the technology would be available for this incredible body tracking option.

The primary disadvantage of inertial body tracking systems is cost. One body part sensor, using current technology, can cost several thousand dollars. As this technology is developed, it is apparent that the cost of each sensor would fall into the range of several hundred dollars, making inertial tracking systems not only desirable, but also affordable.

Best Near-Term Solution:

Inertial Tracking

(see Appendix A for more information)

It is the authors' near-term recommendation that inertial body tracking system research be funded to the maximum extent possible. This technology has the potential to be the absolute best solution for real-time, full human body tracking for synthetic environments.

C. Far Term Recommendations:

It is the authors' opinion that the ultimate body tracking solution will not consist of just one technology. The best body tracking system will eventually (within two to five years) be a hybrid combination of several of the tracking technologies discussed. For example: Although inertial tracking systems solve all of the current problems with the local tracking of the human body, it cannot solve the problem of absolute position of the human body in space.

The ideal "body suit" would be a combination of spread spectrum technologies for overall body position determination, inertial technologies for determining the user's individual body part orientation, bio-feedback technologies for level-of-exertion sensing and CyberGlove-like technologies for detailed hand tracking.

Thus the authors recommend the following for the far-term:

1) **Continued investment in inertial body tracking systems research,**
2) **Continued investment in spread-spectrum position tracking research,**
3) **Continued investment in bio-feedback technology and**
4) **Continued research into technologies feasible for incorporation in a hybrid "bodysuit" to be used as an overall synthetic environment interface device.**

Appendix A
Current Off-the-Shelf Motion Capture Systems

In the following system descriptions, mention is made of a reference human body tracking system (RHBTS). This is a hypothetical device included as a basis of comparison between the current off-the-shelf systems. Although some of the systems described below do not meet these specifications in one area or another, they should not be dismissed out of hand. The RHBTS is only a reference ideal human body tracking system.

The reference human body tracking system specifications are the following:

- Track articulated Human body of 15 segments
- Minimum DOF: 3 DOF orientation or 3 DOF position of each segment
- Minimum spatial resolution: 0.1 inch at 1 m
- Minimum angular resolution: 0.1 degree at 1 m
- Minimum range: 3 m
- Minimum update rate: 30 Hz
- Maximum data latency: 10 msec

Angularis Inertial Technologies

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Method: Inertial

Overview: The Angularis VR-360 system uses three orthogonal angular rate sensors, three orthogonal linear acceleration sensors and a two-axis magnetometer in one small device to determine the angular orientation of the user's head. The system incorporates a unique pause-reset scheme during periods in which the user's head is still to correct the output of the device for gyro drift. The linear accelerometers are also used for three DOF position estimation between head position fixes (a kind of dead reckoning). An additional device must be used for accurate determination of the user's head position.

Interface: RS-232C

Update Rate: 500 Hz
Range: No range restrictions with optional wireless upgrade (otherwise 20 ft)
Accuracy: Unavailable
Latency: < 2 msec

Problems: Cost

Cost: $9,200 (Entire system with one sensor unit for head tracking)
RHBTS Cost: N/A
Guarantee: One year parts and labor.

Comments: Currently used for head tracking only, but is extensible in the near term to track the entire human body. This technology has the potential to be the best body tracking system available, with none of the drawbacks of current body tracking methods. Within one year, components will be available which will make an entire body tracking system realizable at a much lower cost.

Ascension Technology Corporation

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Method:	Electro-magnetic, DC signal, stationary transmitter, multiple receivers
Overview:	The Flock of Birds sensor suite measures position and orientation (6DOF) of one or more (up to 30) receivers relative to the stationary transmitter. The transmitting antenna is driven by a pulsed DC signal which aids in reducing metallic-device interference.
Interface:	RS-232 and RS-488 Supports most systems, including PC's
Update Rate:	100-144 Hz
Range:	1 m (3 ft) with standard transmitter 2.5 m (8 ft) with extended transmitter
Accuracy:	0.1 degree resolution at 1 foot
Latency:	8 msec
Problems:	Sourced, tethered, limited range, limited metallic object interference
Cost:	$2,700 (one receiver)
RHBTS Cost:	
Guarantee:	30 day money-back, no questions asked.
Comments:	Ascension's Flock of Birds system clearly has the ability to track the entire human body in real time. While their method and results are very similar to those of Polhemus, Inc., they claim that their use of pulsed DC magnetic fields, rather than AC, makes their devices less sensitive to metallic device interference.

BioControl Systems, Incorporated

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Method: Bio-electric neural signal sensing (bio-feedback)

Overview: The BioMuse system uses bio-electric signals received from the body via semi-aqueous skin-contact sensors. It is capable of detecting electric signals generated for muscular control (EMG), eye control (EOG), heart control (EKG) and brain waves (EEG). Using these bio-electric signals, the BioMuse system is able to synthesize computer system control signals, allowing the user to control the computer via eye-movements, bodily gestures, etc.

Interface: PC serial

Update Rate: nominally 4 kHz
Range: N/A -- no source
Accuracy: N/A -- no reference for bio-electric signals
Latency: Unavailable

Problems: No ability to detect position or orientation, tethered.

Cost: Unavailable
RHBTS Cost: N/A
Guarantee: Unavailable

Comments: The BioMuse system cannot be used for body tracking as such but, when combined with another means of Human body tracking, it provides valuable information about the user such as, eye-position, facial expressions, bodily muscle tension (representing the user's level of exertion). It is the author's opinion that the BioMuse technology should be explored as a potential complement to ANY method of Human body tracking.

Biomechanics, Incorporated

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Method:	Image-based with passive markers
Overview:	The Biomechanics system uses multiple cameras tracking passive, reflective markers attached to the subject's body. The cameras track the subject in three dimensions, sampling the marker positions at between 30Hz and 60Hz capture rate. The information gathered is then post-processed, with one second of data taking up to one minute to process. Note that this is not a real-time system.
Interface:	RS-232C serial
Update Rate:	30 to 60 Hz capture rate (not real-time)
Range:	10' x 10' x 12' tracking volume
Accuracy:	Unavailable
Latency:	0.1 sec
Problems:	Non-real-time, shadowing, limited work area.
Cost:	Unavailable
RHBTS Cost:	N/A
Guarantee:	Unavailable
Comments:	This system is not capable of tracking an entire human body in real time. It would, however be suitable for post-production motion capture (ie. production animation applications).

Haptek

Contact: Peter Broadwell
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e-mail: peter@meer.net

Method: Mechanical, Exoskeletal with force-feedback

Overview: The HAPTEK system uses an upper body exoskeletal system which senses the users upper body lean and twist, 3DOF shoulder and 1DOF elbow movement. It provides force-feedback from 0 to 80 lbs (user controlled) in response to objects the user encounters in the synthetic environment.

Interface: Uses Macintosh 7100 Power PC for system control

Update Rate: 30 frames/sec in Haptek application
Data update rate in the kHz range.
Range: N/A -- Ground-based
Accuracy: 0.2 degree angular resolution
Latency: 0.1 msec

Problems: User encumbrance (which is necessary for force-feedback), moving parts which suffer from wear, limited work area

Cost: Expected cost: $20,000-$30,000
RHBTS Cost: N/A
Guarantee: Unknown

Comments: The HAPTEK system would be sufficient for applications which require tracking of and force-feedback to the user's upper body. It is not suitable for tracking an entire human body for synthetic environment applications.

Image Guided Technologies, Incorporated

Contact: Kelly Burnham
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Method: Electro-magnetic, moving transmitter, multiple stationary receivers

Overview: The FlashPoint system uses multiple stationary electro-magnetic receivers to detect the output signal of a hand-held digitizing probe.

Interface: RS-232C serial

Update Rate: 200 Hz
Range: 1 m (larger with optional FlashTracker)
Accuracy: 0.5 mm at 1 m
Latency: Unavailable

Problems: Tracks only one point, EM interference

Cost: Unavailable
RHBTS Cost: N/A
Guarantee: Unavailable

Comments: The FlashPoint system may be good for CAD object digitizing but it is not suitable for human body tracking.

Motion Analysis Corporation

Contact:	Jerry Burg
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Method:	Image-based
Overview:	ExpertVision HiRES uses multiple video cameras to capture the motion of a subject placed with passive markers. Complex software analyzes the video data, picks corresponding markers from the images and calculates marker position.
Interface:	PC
Update Rate:	60-240 Hz
Range:	Can cover 25' x 25' area
Accuracy:	Unavailable
Latency:	Unavailable
Problems:	Limited range, shadowing, not suitable for interactive applications
Cost:	Unavailable
RHBTS Cost:	N/A
Guarantee:	Unavailable
Comments:	ExpertVision HiRES would be good for performance capturing for production animation work or study of human body motion but it is not suitable for real time interactive applications.

Northern Digital, Incorporated

Contact:	Margaret Fraser (Andy Johnston)
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e-mail:	margaret@ndigital.com (andy@ndigital.com)
Method:	Image-based, multiple cameras, active Infrared LED markers
Overview:	The OPTOTRAK system uses active infrared markers attached to the subjects body. Multiple cameras track the subject. The markers are sequenced by the system for individual marker identification. A maximum of 256 markers may be simultaneously tracked. An optional device allows untethered operation of the system with up to 254 markers.
Interface:	Interfaces to PC via proprietary interface card. Optional device allows interface to any SCSI-capable computer or workstation.
Update Rate:	3 DOF tracking: 1200 Hz 6 DOF tracking: 100 Hz
Range:	Many ranges overlapping from 0.8 m to 15.0 m
Accuracy:	0.15 mm and .01 degrees at 1 m
Latency:	3 msec
Problems:	Limited range, shadowing and cost
Cost:	$58,000 (one sensor, 24 markers, associated interface equipment)
RHBTS Cost:	$170,000 (three sensors, 50 markers, associated interface equipment)
Guarantee:	One year parts and labor warranty on all components except markers
Comments:	The OPTOTRAK system seems to be the leading technology in optical tracking. Based on Northern Digital's literature, OPTOTRAK is capable of tracking a full human body in real time. The authors were not able to see an operational system while writing this paper.

Phase Space

Contact:	Tracy McSheery
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Method:	Image-based, multiple cameras, active LED targets (markers)
Overview:	System uses multiple CCD cameras to triangulate up to 128 LED's placed on the user's body.
Interface:	Serial, parallel, Ethernet, SCSI-2 Supports most systems, including PC's
Update Rate:	300-500 Hz
Range:	10 m (33 ft)
Accuracy:	1 cm resolution at 10 m
Latency:	6.6 msec
Problems:	Sourced, limited range, shadowing
Cost:	$60,000 (full 6-camera system)
RHBTS Cost:	$50,000 (4-5 camera system will full support for 128 LED's)
Guarantee:	30 day money-back guarantee
Comments:	The current literature on the Phase Space system claims that their device is capable of tracking 128 independent infra-red markers in real time. The authors were not able to see an operational system while writing this paper.

Polhemus

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Method: Electro-magnetic, AC signal, stationary transmitter, multiple receivers

Overview: The FASTRAK and ULTRATRACK systems measure position and orientation (6 DOF) of from one to sixteen receivers relative to a stationary transmitter. Receiver differentiation is accomplished by frequency multiplexing.

Interface: RS-232C and IEEE-488

Update Rate:	120 Hz (one receiver)
	30 Hz (four receivers)
Range:	10 feet (3.1 m)
Accuracy:	0.15 degree angular resolution
	0.03 inch spatial resolution
Latency:	4 msec

Problems: Sourced, tethered, limited range, metallic object interference

Cost:	$6,100 -- Basic FastTrak system with one receiver (4 maximum)
RHBTS Cost:	$32,250 -- UltraTrak 60Hz system with 16 receivers
	$38,250 -- UltraTrak 120Hz system with 16 receivers
Guarantee:	One year warranty on all products.

Comments: Polhemus clearly has devices capable of tracking the entire human body in real time. They are the current leader in the field, with the largest clientelle. The one draw-back with Polhemus devices is their susceptibility to metallic object interference. This is due to their use of AC magnetic fields. Ascension Technology Corp. claims that their use of DC magnetic fields minimizes metallic object interference. The new Polhemus ULTRATRACK system is an entirely integrated system capable of tracking the entire human body (up to sixteen independent segments) in real time.

United Technologies Adaptive Optics

Contact: Anderson Maddocks, Director of Marketing
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e-mail: Unavailable

Method: Image-based, multiple cameras, infrared transmitters, passive markers

Overview: Infrared LED illuminators mounted in a ring around the lens of each camera send a flash which is reflected from passive markers attached to the object to be tracked. The system can simultaneously track from 1 to 100 markers.

Interface: SGI, PC or Macintosh serial

Update Rate: 30 Hz / 60 Hz
Range: 30 m indoor, 8 m outdoor
Accuracy: angular resolution: 1/30,000 camera field of view (FOV)
(Specified camera FOV 7-53 degrees depending on f-stop)
Latency: Unavailable

Problems: Limited range, shadowing

Cost: Unavailable
RHBTS Cost: N/A
Guarantee: Unavailable

Comments: The current capabilities of AOA's body tracking device will only support post-production animation motion capture. It is not yet suitable for real-time track of the entire human body, although they are developing a device which will have real-time capabilities. The expected release date of their real-time system is in the first quarter of 1996.

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